HOBBLE TURNING METHOD AND PREFERRED APPLICATIONS FOR SAID METHOD

The invention concerns a special process for the turning of workpieces and preferred applications of the process. The invention also concerns a screwable artificial hip joint socket designed for cement-free implantation in the human medicine sector.

Description of the Related Art

The principle of conventional lathing is a process which has been known of for many years and is used for the cutting manufacture of workpieces, e.g. of wood, metal or plastic. In recent years, lathing technology has undergone rapid advance via the introduction and continuous development of numerical controls. Thus today it is absolutely no problem any more to, for example, maintain a constant cutting rate along a surface contour. With a suitable program it is now relatively simple to produce even the most complex rotationally-symmetric geometries in very short machining times. Furthermore, machines of this type can be further upgraded by equipping them with tool drives because this allows even complex workpieces to be lathed and milled to form a finished product with a single clamping. Despite this there are certain limitations in connection with certain geometrical configurations or because of the time required. It is for example a fact that lathing in general has considerably shorter machining times than does milling. In addition, turning produces better surface qualities. If as a result of the geometry of a workpiece it is only possible to employ milling techniques, it is unavoidable that either a considerably longer machining period is involved or that an irregular surface has to be accepted. However, this notwithstanding, even milling techniques are subject to certain limitations as far as the geometry is concerned. Thus for example any corner of a milled contour in the radial plane of the milling axis can never have an angle which is more acute than the radius of the milling tool used. And while it may be possible to produce sharper contours using techniques such as broaching, percussion and erosion, it is necessary to move the workpiece to a different machine for this end. In the case of erosion the time requirement is also extremely long. While it is also true that the cutting of non-circular contours has been possible for a

number of years now using profiling turning machines available on the market, these machines are expensive and therefore require a corresponding scale of capital investment. Furthermore such machines can only be connected to the initially intended interface and are limited to the specified contour with two-dimensional ovality.

In the past there have been previous attempts to help lathes machine non-circular workpieces by fitting special mechanical modules. A machine of this type is proposed in the German publication DE 25 15 106. In addition to the very complex and very sensitive mechanical configuration, this machine has extremely limited possibilities which in turn are themselves limited to the generation of two-dimensional non-circular geometries.

The geometrical possibilities for non-circular machining can be expanded with respect to a tool which can be fitted to the lathe if for example the cutting drive can be controlled in a freely programmable fashion. A tool of this type is for example described in the German publication DE 35 09 240 A1. In this case piezoelectric or magnetostrictive actuators are used in order to achieve a dynamic shift of cutting relative to the workpiece using appropriate electronic controls. However, this technique only allows extremely small adjustments to be achieved. While it would be technically possible, for example, to use a magneto-dynamic system to achieve considerably larger control movements, these would as previously be limited to a single movement axis. In order to achieve specific three-dimensional discontinuous machining it would be necessary to add a second or possibly even a third orthogonally arranged movement unit to create a tool with complex directions of movement, whereby this would be of extremely complex design and demand highly sophisticated control electronics. To date a tool of this design is not yet available.

Other special turning machines are also known of which allow the non-circular machining, for example, of pistons for internal combustion engines. Modern pistons have in fact a very slight oval cross section, generally elliptical, in order to compensate

for anisotropic expansion during heating. Having said this, there is however only a very slight deviation from the circular, whereby the contour also has a very gentle crossover. There are no jumps or extreme discontinuities present. This being the case, the constructional design of a machine with this capability does not represent any major difficulty. In principle it is sufficient to allow the tool to oscillate with a slight amplitude on the x-axis of the diameter whilst the carriage traverses the workpiece in the Z-axis. In so doing the path of the tip of the tool will follow a more or less sinusoidal curve such that extreme acceleration is not necessary. This latter would be very difficult to achieve despite the reduced mass of the system. It is pointed out that such machines require a coupling of the workpiece rotation to the movement along the x-axis whereas the advance in the Z-axis can be freely chosen. In fact the generation of the non-circular contour is restricted to the two-dimensional diameter plane and is only extended in a third dimension via the Z-axis. In reality the Z-axis is not actually involved in the generation of the non-circular contour. There is no technique for moving the carriage along the Z-axis in jumps or with for example superimposed oscillation.

A special machine of the type described above is for example described in the German publication DE 40 31 079 A1. In this case it is proposed to control the drive required for the oscillating movement of the tool (for example an electric linear motor or a hydraulic system) by means of an extra computer control in addition to the existing mechanical control, whereby this could be for example a personal computer. However, a machine of this description would be limited in its possibilities to the intended and similar applications unless its basic kinematic process is modified. Furthermore a special machine of this description would be relatively expensive to buy.

SUMMARY OF THE INVENTION

The task at hand was therefore to create a process for the lathing of workpieces with contours which are irregular, discontinuous or abruptly changing contours which on the one hand makes use of the existing possibilities of the machine with compound rest and NC control, also in connection with additional equipment such as linear slides. On the other hand it should overcome inertial problems and at the same time provide the option

of extending the degrees of freedom with respect to the discontinuity of the intended contour by at least one additional dimension. Insodoing a further goal of the new process is as far as possible to waive the need for the previously necessary milling operations.

The task referred to is solved by the invention using a turning process which is described by the applicant as jerk lathing. In this the workpiece is rotated in the chuck of the machine spindle at a preferably constant speed of rotation during which the compound rest with the optionally fixed or controllable cutting tool is moved along the chosen axis, e.g. the pitch axis using a e.g. thread or C-axis program synchronised to the spindle axle to generate specific non-circular contours made up of combinations of geometrical transitional elements using a program of jump functions by linking command blocks with values for selected address parameters e.g. diameter (X), length (Z) and either angle (C) or pitch (F) whereby for at least one of these parameters in the program block chain a sequence of jerk value groups is used with at least one numerical value in each value group. This process can be expanded by including the parameter height (Y) in suitably equipped machines.

In order to generate a specific tool track relative to the workpiece the over-shoot, the inertia, contouring error and the nominal all rigidity of the components concerned are all specifically exploited. However, it is in particular proposed to generate a tool track which only partially corresponds with the required discontinuous contour. It is then possible to either remove the non-required, or unusable sections or those sections non-compliant with the specifications in a follow-up machine cycle e.g. by milling, or to correct the contour to achieve the final contour using subsequent jerk machining. IN the case of certain tasks it is especially advantageous to employ a jump system in accordance with the invention in which the discontinuity to be created using interleaved sequential sequences of comprising geometrically opposed staggered lathing cycles.

When programming the control in accordance with the invention to generate the required tool movements in most processing tasks the increments formed between the numerical values for at least one address parameter in the program block chain represent a jerk sequence of value groups with at least one numerical value in each value group, whereby for example the corresponding numerical value within one value group is larger than that within the other and/or the sign within one value group is positive and within the other value group is negative. In principle the program values in the program block chain for a certain address parameter form a sequence of numerical values in which the commanded jump function is expressed as jerk steps. Insodoing the respective target coordinates can be plotted as dots on a curve whereby a they are connected by straight lines. It is part of the nature of the invention that in those sections of abrupt contour changes in particular the tool track generated will not to be compliant with the straight lines but will approximate the straight line in the form of rounded transitional functions.

The special significance of this process is its applicability in all three dimensions, even without the inclusion of the height axis (Y). This machining freedom is due to the fact that the jerk steps can be programmed via X, Z, F and C either singly or in combination with one another as well as in connection with a tool with linear drive.

In its simplest form the process in accordance with the invention dose not require either special equipment nor additional NC controls. It can be realised based solely on the use of the possibilities provided by the machine control and appropriate software and is only limited by the dynamics of the overall system. This can comprise for example the known command blocks G 01, G31, G 33, G 34, G 37 or G 131 etc., whereby for example address parameter diameter dimension (X), longitudinal dimension (Z), thread pitch (F), start-up length (B), overshoot length (P), start-up angle of the spindle (C), reference direction for F (H) and change in pitch (E) may be used or by inserting blocks with special software. The possibility is also not excluded that based on the process

proposed here the industry will in the future offer expanded programming possibilities as standard.

When driven special tools are not utilized, the dynamics described above of the overall system is made up of the mechanical and electronic dynamics of the machine. The mechanical dynamics is dependent upon the mass of the compound seat and on the response speed of the drive, e.g. comprising threaded spindles, motors and gears. In contrast the electronic dynamics is dependent upon the speed of the control processor and its links with the electrical motor drives. It is therefore the case that lathes of the latest generation equipped with digital drives and the fastest computers are suitable for extreme machining of ovality whereas the application of this process on older machines will have corresponding restrictions. These restrictions can to a certain extent be partially overcome by the use of reduced cutting speeds during lathing because this results in lower spindle speeds and also correspondingly reduces advance speeds.

A very simple application of this process comprises for example the lathing of eccentric journals. In this case for example an angular resolution of 180° is realised with respect to the workpiece by, for example, linking command blocks, e.g. in this case G 33, by in each case programming the start-up co-ordinates in X and Z and a pitch in F whereby the increments lying between the programmed Z values of in each case 180° for the angular step referred to must in principle have a value of half of the programmed pitch value. In contrast, the values for X for each 180° half step vary backwards and forwards between a larger and a smaller programmed diameter value, whereby in theory the average value corresponds with the diameter of the journal and the half difference corresponds with the eccentricity of the journal. In order to simplify the programming work, it is possible for example to enter the repeating jumps in the Z or in the diameter axis in some controls as a variable. Since in the example described the diameter change is generally larger than the intended advance, in this case the pitch, in a normal case the machine control will deduct the programmed pitch against the advance on the X-axis. Therefore it is necessary that for the pitch, the value F - i.e. the path

programmed with respect to the diameter per rotation - must be entered as double the diameter difference, unless the reset is prevented by command blocks, e.g. with H. The programming described produces a theoretical track curve of the compound seat having the form of an extending zigzag line. In effect, however, because of the various ameliorating factors, e.g. the high mass of the compound seat and the insufficient rigidity of the control loop, the movement of the compound seat during advance along the workpiece is actually a continuously repeated quasi-sinusoidal curve such that despite the in principle primitive programming a remarkable roundness of the eccentric journal is achieved. On the other hand this distortion means the measurable dimensions of the workpiece do not correspond exactly with the programmed values. It is therefore necessary to determine the actual programmed numerical values based on trial workpieces. Based on these it is, however, possible to reproduce the dimensions with high precision on the machine concerned.

The procedure described above is applicable for the turned production of elliptical bodies, in that the programmed zigzag curve is specified with a double resolution, i.e. with angular steps of 90°. In this case the two alternating program diameters describe the theoretically maximum and minimum diameters of the ellipse. It is then necessary to program the pitch which is usually calculated by the control along the X-axis with a value of four times the diameter difference.

A similar procedure is then adopted if it is intended to produce a polygon (a so-called orbiform curve) whereby the resolution of the angular step must be 60°. Machining of this type is for example interesting in the production of face-side cut grooves, as used today for example as the lubricating groove of starting discs or the cleaning groove of disk brakes. Proper functioning in these cases does not require precision machined groove tracks, such that any track deviations can be neglected.

The examples described above are concerned with relatively harmonious non-circular items with a constant advance in the longitudinal axis with fixed and programmed pitch.

It is easily possible to extend the programming described by the addition of auxiliary points in order to produce perfect contours. The process in accordance with the invention can be extended considerably further because it enables extreme jump machining of the workpiece, also along the longitudinal axis.

To achieve this result it is proposed to use cutting techniques to produce workpieces with even greater in particular spatial discontinuities and with angular contours or to achieve higher degrees of track precision by bringing in variable or stepped pitch values, for example also in connection with a finer resolution of the contour. In the program the track to be followed by the compound seat in order to achieve a specific contour is described in the form of linked blocks, e.g. with G 33, with a different pitch specified in each program block whereby in extreme cases, e.g. a very small value for F followed in the next program block by a very large value for F results in for example a sequence of soft then abrupt movements of the compound seat. This process allows the lathing of discontinuities of great diversity to be achieved for example also the surface shell of curved bodies. It is possible in a similar fashion to use this process to achieve discontinuous contour outlines as described by using co-ordinate chains programmed in the program block made up of only respective X and Z values or also in connection with F values. Thus for example the advance in one or both axes can be programmed as pilgrim-steps whereby after a certain advance movement there follows an in each case abrupt (shorter) return jump which is in turn followed by for example a larger advance distance. In this sense such a process can for example be understood as being the alternating cutting of linked right and left hand threads with under certain circumstances asymmetrical thread pitches.

The process in accordance with the invention also allows the cutting of discontinuous contour elements protruding from an angled or curved surface shell whereby the side of the tool predominantly works the flank of the discontinuous contour element and the tip of the tool predominantly cuts the surface shell. In this case suitable programming of start and finish points and pitch allows the tip of the tool to be controlled along a track

which for the most part runs tangentially to the surface shell and the side of the tool generates the flank of the discontinuous element controlled by a programmed change of the travel speed and/or travel direction.

In the programming described particular care must be taken to ensure that the reference direction for F, which is generally described with address parameter H, is correctly used. As is known, H describes which axis is used to calculate the advance which corresponds with the thread pitch programmed under F. Without other specifications or where H = 0, the advance refers to the Z-axis, i.e. in principle to longitudinally, conical and similarly linked threads up to maximum 45° to the Z-axis. If H = 1 then the advance calculation now refers to the X-axis, i.e. to basically planar, conical and correspondingly linked threads of maximum 45° degrees to the X-axis. In this case H = 3 refers to movement on the thread track. In the case of linked threads on curved surfaces it can easily occur that the limit value of 45° is exceeded and the machine control then automatically springs over to the other axis calculation. This must be either determined for example by conversion and be deliberately falsified in the program or this reset must be prevented by appropriate software in the event that the control system has such a command block available, e.g. with I for a face pitch and K for a longitudinal pitch.

To complement this the programming of the target coordinates X and Z in connection with the pitch F using a command block for threads (e.g. G 33) has the problem that the actual pitch of zero will not be accepted by the control. One possibility of overcoming this obstacle is to set these parameters to the minimum programmable increment (e.g. 0.001 mm).

In the case of the invention, however, there is an even more elegant method to eliminate this problem whereby this also simultaneously avoid the reset at 45° as well as reduces of the programming work. In this method the jerk program e.g. in command block G 01, is specified in the form of coordinate chains of X and Z, and the spindle

angle C. This waives the need for calculation of the respective pitch because this is derived from the difference between the in each case selected reference parameters (Z or X) in relation to the spindle angle C. In the case where the angular steps between sequential spindle angles in the command blocks are the same or all repeat themselves within a specific regularity, e.g. as a jerk rhythm, then the value for C can be programmed as a variable. In this case the parameter is either raised or lowered in value, after completing of the respective program block, by an amount equal to the respective angular step value which can also be programmed as a variable or as a fixed value. In the event that changes are required to the under certain circumstances extremely long programs, it is then generally possible to modify only a smaller number of fixed values or variables.

The process described above for spindle programming is however only suitable for certain machines and NC controls which are compliant with state-of-the-art developments. In these machines the spindle is integrated in the drive motor whereby the entire unit can be addressed either as the turning axis or as the C axis. With correspondingly fast NC controls there is a certain degree of a equivalence with respect to programming between the speed of turning of the spindle, which is for example expressed in that the C axis can be used even at very high rpm (under certain circumstances several thousand rpm). This means that the programming of the C axis allows cutting speeds to be achieved which are comparable with those of standard lathing operations.

The overall process according to the invention is further extended by the proposal to overcome application limitations due to the restrictions of machine dynamics or of the linear driven tool in that for extreme machining geometries an interleaving of the processing sequences is employed. This refers to a kind of jump process in which for example a first machining cycle processes a first contour element but which at the same time also skips a second in order then to follow a third contour element when its tracking has steadied, and so on. The contour elements missed out of the first machining cycle

are then cut in a second machining cycle, whereby the contour elements of the first machining cycle are now skipped. This process takes into account that the overrun of the overall system as a result of an abrupt movement programmed at maximum traversing speed means that the overall system is not able to track a contour element which follows at a close distance and will not be traversed in the desired manner. Although in order to execute the process two or more machining cycles may be required, which takes longer, this nevertheless represents a drastically shorter time than that required by milling techniques.

Together with the invention preferred applications of the process are also proposed. These applications also serve to provide a more detailed explanation of the process based on a number of application examples.

The proposed application concerns the production of threads for diverse, in particular self-tapping screw-in bodies into yielding materials whereby such bodies are e.g. wood, plastic and bone screws including e.g. implants such as hip bone screws, fusion bodies, screws for fixateur externe, screw in posts for dental implants and artificial hip joint sockets.

A further application is the inexpensive manufacture of so-called circular wedges profiles on the internal or external coupling faces of coupling elements in mechanical engineering.

One of the above proposed applications refers preferentially to self-tapping artificial hip joint sockets for cement-free implantation into humans. These kinds of screw-in sockets are available in the marketplace in various designs. In order to ensure reliable and permanent integration and also simplified handling during implantation surgery the design of the thread is of primary importance. It is known in the interim that a large contact area of the implant to the bearing surface without stress peaks and a threaded profile inclined towards the pole of the socket help create the best preconditions to

avoid loosening. On the other hand, such a screw-in socket must provide good tactiliance, which is a term which describes the "feel" of the surgeon for the seating of the socket body on the prepared bone surface in the Acetabulum during the screwing in of the screw-in socket. In existing screw-in socket types there is a need for improvement because they either leave undesirable free spaces to the bone interface after implantation or can only be screwed in with excessive force or their tactiliance is insufficient.

One group of screw-in sockets is configured with a so-called flat screw in which the lateral surfaces of the thread rib are parallel to one another. It is standard procedure to interrupt the thread web by machining cutting grooves at certain intervals in order to form cutting edges. In this type of thread the cutting force during self-tapping must be applied totally via the radial head surface of the thread rib which is inclined outwards or by any cutting edges which are in situ there. When these other measures are undertaken, however, the head surface of the individual thread blades describes a spiral curve in the axial view of the pole-side of the screw-in socket, the exact track of which is dependent on the form of the shell body of the screw-in socket and the pitch of the thread. As a result the radial curve spacing from the polar centre increases with progressive turns. The end of any one thread blade is therefore at a greater radial distance outwards than at its start. This means that during screw-in of such a screw-in socket a pinching effect is created which can only be ameliorated by the filing forces of the roughened surface of the implant on the bone material. This means that implants of this design have unnecessarily high screw-in forces.

On the other hand, screw-in sockets are available with a flat thread, the threaded blades of which have a relief angle created by over-milling in groups. However, as a result of the machining technique chosen, a number of straight head-side surfaces are created which run back as chords which are offset to the respective swing circle formed by the respective cutting edge. This means that although screw-in sockets with this kind of thread are relatively easy to screw in they only have a reduced contact area to transfer

forces because of the shortened thread tooth height. A special disadvantage is the formation of gaps in the area of the thread tooth head, between the implant and the bone, as well as the leverage forces acting on the bone substrate because of the excessively deep cut of the tooth flutes. This is the reason why screw-in sockets of this type are also deemed medically deficient.

Screw-in sockets of the type described above with a flat thread have only been able to claim a small fraction of the market to date. At the present time, screw-in sockets with so-called pointed threads are more widely spread. However, these products are burdened in principle by the previously described problem complex with respect to unacceptable screw-in characteristics and the formation of a gap in the contact zone. The various attempts made to reduce the screw-in forces have actually, amongst others, resulted in a excessive widening of the milled cutting grooves to the detriment of the threaded blades. This means that valuable contact area is lost in conjunction with the formation of extended cavities and also reduced osary areas to absorb the forces.

In US patent 4,997,447 a screw-in socket with round thread flutes is proposed in which the head surfaces of the individual thread blades run in a curve, whereby a relief angle is realised which reduces as the radius of this curve, seen from the socket pole, reduces with increasing distance from the cutting edge. In this screw-in socket, the degree of gap formation relative to the straight head surfaces is noticeably reduced without any loss of good screwing properties. However, this configuration does also not result in a full bone contact of the individual thread blades in the respective rear zones. Furthermore to the manufacture of this product is extremely time-intensive, because the proposed design requires the complete traversal of the tooth head length with a milling machine.

Up to now, no products are available on the market in which screw-in sockets with pointed threads have individual thread segments with a relief angle. This is thought to be in connection with the fact that the implementation of such a design is extremely

difficult and the initial choice of adopting milling techniques for production would require not only extremely complex programming but also very extensive machining times. These problems are due to the problem that in the case of pointed threads and depending upon the pattern of the cutting grooves at least one of the lateral surfaces of the thread tooth must be used to form a cutting edge. If, however, a neutral or relief angle is to be formed behind the cutting edge then the corresponding lateral surface of the respective thread blade must be backmilled to the subsequent cutting groove at a congruent lateral angle. This creates the problem that the milling machine cannot machine curved surface shells while simultaneously following the contour of the base of the thread flute. One has then the choice of either accepting an increasing groove-like depression along the flank of the tooth or a correspondingly large stepped residual relict. In cases where this relict is unacceptable, it would then have to be removed subsequently using at least one additional milling run.

With the process in accordance with the invention it is, however, possible to cut such threads for hip joint sockets with great perfection in a short time using lathing techniques. In so doing it is irrelevant whether the discontinuity machining to create a certain pattern e.g. a relief or neutral angle of the individual thread blades is to take place on its pole, its equator or its head side surface or on several of the surfaces. Because of the free programmability of the machining track it is not only possible to master any desired profile of the thread tooth but even the angular pattern of the generated thread rib sections are virtually freely selectable in three-dimensional space. At the same time the entire thread can be perfectly adapted to the outer shell of the socket body. Thus the invention can be applied to all known shell forms, e.g. spherical, aspherical, parapherical, conical-spherical, conical, cylindrical, parabolic, toroidal, etc.

The process according to the invention can be simply combined with other well-known processes for the production of threads for hip joint sockets, e.g. with the process as described in European patent EP 0 480 551, or with the process proposed in German publication DE 44 00 001 for the production of a thread with modifiable thread profile. A

particularly beneficial combination appears to be a thread tooth profile inclined towards the socket pole and a thread pitch which changes smoothly in accordance with international patent application WO 97/39702.

It is suggested in this regard in the invention that for artificial hip joint sockets with a tooth profile which tapers towards the head of the thread tooth, that the thread blades formed between the cutting grooves are produced as so-called screw surfaces (sometimes referred to as screwed surfaces) and to selectively swivel them in their respective direction of extension depending upon the windup of the cutting groove. In this case screw surfaces are understood to mean those surfaces which are created by the rotation of a certain tooth profile with constant radial distance from the axis of the socket and with a pitch around this axis. In the case of for example trapezoidal tooth profiles this would mean three screw surfaces are formed, one on the head side and two on the lateral sides. Insodoing, these screw surfaces can be shortened in their base area along their extension if the tooth profile runs into the surface shell for certain shell geometries of the screw socket. The surfaces which follow the cutter at the start of the respective threaded blade will then have a neutral angle, i.e. neither a pinch nor a relief angle. This then avoids the undesirable pinching effects while at the same time ensuring bone contact on all sides of the threaded blade. In order to enable the cutting edge to have the optimum effect at the start of each respective threaded blade, it must protrude compared with the leading threaded blade. In the first step this is achieved in that a larger radius is selected for the screw surfaces of a following threaded blade than for the screw surfaces of the leading threaded blade. Preferably, the individual threaded blades are swung relative to one another in their extension as a function of the windup of the cutting grooves, whereby the preferred direction of swing is one which approaches the windup angle in order to realise an overstand of the lateral cutting edge with a positive cutting angle.

Another practical implementation of the invention in the production of these types of threads is to generate overshooting transition functions of the cutting track in specific

positions on the thread length by programming jerk-jumps and to synchronise these with some form of interruption, e.g. in the form of cutting grooves such that during milling of the discontinuity the interfering or unusable parts of the contour generated are removed and that the cutting edge following the discontinuity in the direction in protrudes compared with the tooth profile. Of the remaining part of the tooth blade than drops back compared with the cutting edge such that behind the cutting edge an area corresponding with a free angle is formed.

A further application of the invention concerns so-called circular wedges (or 3K couplings) in general mechanical engineering. These comprise a friction contact expanding coupling, for example between shaft and hub, which is a self-locking but releasable connection.

In the case of a circular wedge coupling, and in contrast to cylindrical cross-pressure locks, the joint connecting areas of the shaft and the hub are not round but have so-called wedge surfaces on the circumference. Generally there are three wedge surfaces. They comprise identical and reciprocally opposed turned sections of spirals, e.g. logarithmic spirals. When clamping by turning through a certain relatively small angular amount (e.g. 15°) the necessary homogenous contact surface is achieved and hence the maximum possible frictional connection between the shaft and the hub. Circular wedge coupling also provide for an excellent transfer of the respective forces and boast an advantageous rigidity of configuration. A coupling with three circular wedges on the circumference is self-centring. If the radial pitch of the wedges surfaces is selected between 1:50 and 1:200 circular wedge couplings are generally also self-locking.

If produced in sufficiently large numbers and if the technical requirements are not too demanding circular wedge profiles can be produced without cutting and hence relatively inexpensively. On the other hand relatively smaller numbers and to fulfil higher quality demands has to date required either milling or grinding techniques with correspondingly high costs. The diameter of the milling tool or of the grinding disk results in the creation of transitions to the individual circular wedge areas which are unusable. In conjunction

with the angle of twist required relative to the joints this means the coupling can only be transfer a fraction of the potential forces.

Using the process in accordance with the invention circular wedge couplings of this type can be manufactured using interleaved machining sequences with greater precision and at lower costs, even in small production numbers. The option is also created of machining couplings of this kind with a conical design if required.

a

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is described in more detail with respect to the preferred applications based on seventeen schematic drawings. These are as follows:

Fig. 01	Hemispherical screw-in socket with flat thread pinching on the head side in accordance with state-of-the-art technology
Fig. 02	Hemispherical screw-in socket with a flat thread with a relief angle in accordance with state-of-the-art technology
Fig. 03	Hemispherical screw-in socket machined in accordance with the invention with a flat thread made up of threaded blades with head-side screw surfaces
Fig. 04	Hemispherical screw-in socket in accordance with the invention with a pointed thread made up of threaded blades with screw surfaces on all sides
Fig. 05	Two threaded blades of the screw-in socket in accordance with fig. 1
Fig. 06	Two threaded blades of the screw-in socket in accordance with fig. 2
Fig. 07	Two threaded blades with relief angle and arc-shaped head surface
Fig. 08	Two threaded blades of the screw-in socket in accordance with fig. 3
Fig. 09	Two threaded blades of the screw-in socket in accordance with fig. 4
Fig. 10	Three threaded blades of the screw-in socket in accordance with fig. 3 and high-dynamic tool track
Fig. 11	Three threaded blades of the screw-in socket in accordance with fig. 3 with a tool track of average dynamics using the jump process

Fig. 12 Three threaded blades of the screw-in socket in accordance with fig. 3. and over responding tool track with the jump process

Fig. 13 Theoretical tool track generated with jump commands

Fig. 14 Workpiece contour generated form transition functions

Fig. 15 Final workpiece geometry after further processing

Fig. 16 Sleeve for a circular wedge coupling

Fig. 17 Journal for a circular wedge coupling

DETAILED DESCRIPTION OF THE INVENTION

The drawing in figure 1 presents the pole-side view of a hemispherical screw-in socket 1 with a flat thread in accordance with state-of-the-art based on an example with 1.3 magnification. In the example the nominal diameter is 54 mm, the average tooth height is 2.6 mm, the pitch is 5 mm and the base hole diameter is 22 mm. These basic dimensions were selected for technical drawing reasons and are also retained in drawing figures 2 through 4 to allow better comparability. Similarly, the windup angle of the cutting groove has been set at 0° throughout in order to reduce the drawing work. It is known that a woundup cutting groove offers advantages with respect to a more favourable cutting angle and a more evenly distributed transfer of forces.

A dome shaped thread-free area 6 on the shell body continues from the base hole 9 of the screw-in socket 1. In the drawing the diameter of the shell body is represented only by the equatorial margin area 10. The thread starts on the pole side at first thread blade 7 and reaches its full height before threaded blade 2. Two of the threaded blades (2, 3) are marked with identifying numbers and are further detailed in detail drawing figure 5. Both the head-side surfaces (4) and the edges (5) formed at the base of the tooth at the shell body of the individual threaded blades – with the exception of the starting and end zone of the thread length – appear to be on a spiral-shaped curve in the two-dimensional drawing. The overall thread length has approximately 4 circuits. The thread base 8 running between the thread blades forms the hemispherical shell of the shell body. In order to create cutting grooves (11) or cutting edges, the circumferential

threaded rib is slotted twelve times without wind-up. In so doing the slotting dips at an angle of around 10° in order to form in each case a positive cutting angle at the thread tooth head.

The example shown in figure 2 of a screw-in socket with a flat thread in accordance with state-of-the-art is produced from screw-in socket 1 by after-milling. In the diagram the base hole 20, the dome area 17, the thread base 19, the nominal diameter 21, the slotting 22, the edges (16) between the threaded blades and the shell body all correspond completely with figure 1. In order to maintain a constant average threaded tooth height the threaded blades were individually milled because of the hemispherical shell body. In so doing the pole-side start of the thread moved to threaded blade 18. The straight outer areas 15 of the individual threaded blades now run as chords to the swing circle of the leading head-side cutting edges in the screw-in direction and in synchronisation with the thread slotting such that relief angles are formed with respect to the respective swing circle. The effect of the cutting edges, of reducing the screw-in forces, is achieved by the circumstance that the radial distance of the cutting edges from the socket axis is always larger than the corresponding radial distance of the leading edge of the blade. Two of the threaded blades marked 13 and 14 are detailed below in figure 6.

The example illustrated in figure 3 is a screw-in socket 23 machined in accordance with the invention process and corresponds in its hemispherical shell, its basic dimensions, base hole 31, dome area 28, the edge 27 between the threaded blades and the shell, the base of the thread 30, the diameter 32 and the thread slotting 33 with the example in figure 1. The thread length of the flat thread starts with a reduced tooth height in the first threaded blade 29 which then increases in jumps in the next sequence of four threaded blades until the threaded rib reaches its full height in threaded blade 24. The parallel flanks of each individual threaded blade border in each case on the outerlying section of a cylindrical surface 26 which is coaxial to the screw-in socket axis, whereby the basic cylinder diameter increases in steps from threaded blade to threaded blade.

This design principle can also be achieved with a respective section from a correspondingly coaxial screw surface. This design as described forms neither a pinch nor a relief angle at the threaded blades. Indeed a relief angle is absolutely not necessary because the surface roughness (e.g. caused by sand blasting of the screw-in socket surface) creates filing forces which, assuming a neutral relative movement, prevent any sticking during the screw-in process. This means the undesirable formation of a gap between the implant and the bone layer is avoided. Despite this, the front outerlying cutting edge of the threaded blade is effective because it has a larger radial distance from the socket axis than the leading cutting edge. This results in slightly lower screw-in forces with average tactiliance and improved primary and secondary fixation of the implant.

The example of a hemispherical screw-in socket 34 machined in accordance with the process in accordance with the invention is illustrated in figure 4. Here again the various individual details, i.e. the base hole 42, the dome area 39, the base of the thread 41, the diameter 43 and the thread slotting 44 are the same and unchanged from the previously described examples. In contrast to these, however, the thread described is a pointed thread comprising in principle a triangular thread tooth profile. This fact is not apparent from the two-dimensional drawing. In a similar fashion to above, the thread length commences with an initial small thread blade 40 and the tooth height increases over several stages and reaches its final (average) tooth height at threaded blade 35. The edge (37) formed by the tooth head, which in the case of a pointed triangular cross section of the threaded tooth is practically only a line, comprises for each individual threaded blade a screw line with constant distance from the axis of the screw-in socket which is shown in the diagram only as an curve with a fixed radius to the socket centre. In the case of the pointed thread chosen, the lack of windup of the cutting groove 44 means a cutting edge is formed at both thread tooth flanks. The cutting edge would shift to one of the threaded tooth flanks if the cutting groove had a corresponding wind-up. The surfaces on both sides of any individual threaded blade of the example shown comprise screw surfaces whereby the pitch of the pole-side surface corresponds with

the pitch of the equator-side surface even if the optical impression seems to indicate otherwise because of the socket diameter which increases towards the equator. Because of this, the edge 38 formed at the base of the tooth between the threaded blade and the shell of the screw-in socket appears to run backwards into the shell. After adopting a larger radial distance from the socket axis for the screw surfaces of the next subsequent threaded blade during screwing in, the cutting edges on both side can be either lateral to the thread profile of the leading thread blade or protrude radially outwards and will as such cut easily during screw-in. In this case again, the neutral angle created by the extension of the threaded blades means that the creation of gaps in the contact area to the bone is avoided.

The statements made in the preceding on state-of-the-art and on examples of the process in accordance with the invention are explained in greater detail in the magnified details presented in the following figures because certain details are only difficult to recognise in the overall diagrams.

In figure 5, two threaded blades 2,3 are enlarged from figure 1. Of these, threaded blade 2 has a cutting edge 45 located on the front of its head-side surface 46 and threaded blade 3 has a identical cutting edge 47 on the corresponding surface 48. The swing circle 49 which has a fixed radius around the central axis of the socket and which is described by cutting edge 45 during screwing in of the screw-in socket is marked in as a dot - dash line. It is easy to see that part of the respective threaded blade extends beyond the swing circle, which in general will lead to blocking effects.

Figure 6 shows details of threaded blades 13, 14 in accordance with the example illustrated in figure 2 and will not result in blocking effects because the surfaces 51 and 53 on the head side following cutting edges 50 and 52 are milled with a relief angle. Insodoing the dash-dotted swing circle 54 of cutting edge 50 does not touch the head-side surface of the threaded blade at any point. It is, however, true that each of these cases creates undesirable free play. This free play is larger, the smaller the number of

cutting grooves. This means that in particular screw-in sockets with for example only six cutting grooves will be extremely disadvantaged. The design shown is frequently used for conical screw-in sockets because then the threaded blades can be very rationally milled in so-called packages. Medically speaking, however, this argument bears no weight and should be rejected.

The problem described above can be ameliorated to a certain extent by adopting a design of the threaded blades 60, 61 in accordance with figure 7. Here again the head-side surfaces 56, 58 of the threaded blade have a relief angle with respect to the swing circle 59 behind the leading cutting edges 55 and 57, this effectively prevents jamming during screw in. However, because of the curved shape of surfaces 56, 56, the gap-forming free play is relatively small and is therefore more acceptable. On the other hand, however, this arch shape is concomitant with a much greater milling complexity and effort because the individual threaded blades have in principle to be tangentially traversed individually during manufacture. In the process according to the invention the geometrical configuration illustrated of the individual threaded blades can be produced much more rationally in only a single clamping on a CNC lathe.

In comparison, the configuration of the respective outer surfaces of the individual threaded blades as so-called screw surfaces using the process in accordance with the invention, and as described previously in figure 3, is shown in figure 8 in the form enlarged depictions of two threaded blades 24, 25. The head surfaces 63/65 of the threaded blade extending from cutting edges 62 and 64 respectively have a fixed radius which is defined in each case as the distance of the cutting edge from the screw in socket axis 67. Therefore the swing circle described by cutting edge 62 and depicted in the drawing as a dot-dash line with fixed radius 66 is coincident with the head surface 63. Since the corresponding radius of threaded blade 25 is larger, its cutting edge 64 extends beyond the leading cutting edge 62 of threaded blade 24 during screwing in. This means that the respective cutting edge and the subsequent front area, set at a

positive cutting angle, both penetrate/cut into the bone material and can transport the cuttings away in the cutting groove with a relatively light cutting force.

The situation in figure 9, showing an enlargement of a section of figure 4 differs from that described in figure 8 in that the thread does not have a flat thread in its tooth profile but a pointed thread. Here again, however, the outer surfaces of the individual thread blades 35, 36 are each designed as screw surfaces. Because of the inclined lateral angle and the pitch or the angle of the threaded blades, and the hemispherical shell contour, the edge formed at the base of the tooth to the shell jacket appears to run into the shell body at its rearward end 73, 74. In fact, however, when the screw-in socket is rotated there is no radial shift of the projected tooth cross section because the respective outer edges 69, 71 are unchanged in their radius to the screw-in socket axis. By bringing in a triangular tooth cross section for the example shown, there is a shift of the respective cutting edge of at least one lateral surface of the respective threaded blade, and in the case of cutting grooves without wind-up, on both lateral surfaces. The drawing shows only the pole-side cutting edges 68, 70. The respective rearward cutting edge is hidden. The swing circle of the head-side threaded tooth edge 69 is shown with fixed radius 72 around the screw-in socket axis 75. The extremely reduced screw-in forces of this design are the result of the mutual radial offset of the individual threaded blades as a result of which the individual cutting edges stand out both laterally and outwardly compared with the respective leading cutting edges.

In order to understand the procedure to implement the process for the proposed preferred application for the production of a screw-in socket thread the features presented in figures 3 and 8 are again referred to in figures 10 through 12. In each of the figures the three threaded blades 24, 25, 76 of the flat thread are depicted as is cutting edge 62 on the head-side surface 63 with its dash-dot swing circle 77, with the radius 66 around the screw-in socket axis. The scale of the figures is slightly reduced compared with the preceding figures.

Figure 10 illustrates the track 78 of a machine tool (e.g. indexing cutter) which is equidistant to the head-side surfaces of the individual threaded blades, whereby the track is achievable in the configuration shown using a program in accordance with the invention comprising a small number of target points with an extremely dynamic lathe or a correspondingly dynamically driven tool. The distance of the track from the contour to be cut was selected in order to make the course of the track visible over its entire length. Track 78 contains two discontinuities 79 and 80 which are deliberately placed in those positions by the programming in order to allow subsequent machining of the slotting of the thread using milling techniques. Although the discontinuities 79, 80 of track 78 are transitory in function, it has the effect of creating a radial jump function between sequential threaded blades. This radial jump function exists in every case with respect to the proposed programming whereby at least two sequential following co-ordinates of the same diameter have to be entered with a traverse in Z adapted to the machining task and a suitable pitch or suitable spindle angle and followed by a diameter jump at maximum advance speed (e.g. 100 mm/rev). In order to achieve an acceptable machining result it is necessary that the transition area on the workpiece is not wider than the intended width of the cutting groove.

The creation of the cutting track as shown in figure 10 is not even possible using a linear drive tool because the overall dynamics of the system are insufficient in order to move any compound seat with the necessary precision within the required path on a different lathing diameter. With the invention the proposal in this case is a jump process with which this problem can be overcome in principle. The corresponding theoretical background is clarified in figure 11. The machining procedure for track curve 81 suggests only machining for example the 1st, 3rd, 5th, 7th etc. threaded blade in a first machining cycle and skipping the 2nd, 4th, 6th etc. In this case the transitional function of track 81 arising from the programming of the jump function and in connection with the machine damping need only be sufficient such that after point 82 the reaction is for the tool to be lifted over the next following cutting edge merely enough not to round it off or damage it. There is room up to point 83 to return the tool to the desired track, and this is

not limited by the width of the cutting grooves. It is then possible without difficulty in a second machining cycle to complete the contour elements skipped and to similarly skip those machined previously.

In the case of older lathes with corresponding inertia in control circuits it must be taken into account that an over-response will result in a distortion of the track curve. This effect is shown clearly in track 84 in figure 12. Following the abrupt reaction of the tool movement to the programmed task at point 85 there is an over-oscillation of the track which reaches its maximum at point 86. This is then followed by a soft build down transition until the track is again on the programmed course at approximately point 87. In this example the described effect would still be just about controllable using the suggested jump process in two machining cycles. If necessary the jump process could, however, be extended to comprise of three or more cycles.

The variations as above describe a process which is equally applicable to inclined tooth head surfaces as well as to the lateral surfaces of threaded blades, for example as per figure 9. In this the described jump function is shifted either completely or partially from the X-axis to the Z-axis. In these cases the jerk tracks described by the tool have not been illustrated in the drawing, but do correspond in principle to those jump processes shown for the machining of tooth heads.

As described previously the invention also opens up the possibility of directly exploiting the overshoot behaviour of the machine for the creation of relief angles on thread blades. The exact procedure is described in more detail in figures 13 through 15. Figures 13 through 15 show three curves on an enlarged scale based on the example of staggered tooth flank which have been reduced to the interesting movement section of the tool track for transparency by leaving out the spatial components. In practice the this movement could be on one or more levels.

Figure 13 shows the tool track 88 commanded in the program using a single jump command. Coordinate points 89, 90, 91 and 92 are specified using corresponding values for X and Z. Of these only the modification of Z is a shown on the drawing sheet as vertical components, whereas the respective value of X is not apparent in the drawing. The horizontal spacing between the coordinate points is proportional to the respective spindle angle, which can be programmed either directly via parameter spindle angle C or indirectly via the pitch (F). In so doing it should be noted that if parameter F is also used the maximum permitted the value of the pertinent NC control must not be exceeded, whereas in the case of the spindle angle programming of the angular jump, 0° can be set without problems. In principle a number of jump commands can also be linked with one another.

Figure 14 shows that the configuration of a threaded tooth flank measured on the workpiece before the milling of the cutting groove, as results from the command chain as per Figure 13

The curve 93 in the figure comprises of transitional functions which are based on the inertia and the standard rigidity of the machine and the control. The curve starts with a smooth transition 94, and is abruptly redirected at point 95, in synchronisation with the jump command. The point of maximum overshoot is point 96, which is followed by a return swing 97. After this there is a small amplitude residual swing 98 before the curve returns to a steady line 99.

Figure 15 shows the lateral workpiece contour after the production of the cutting groove. The flanks of the cutting groove are indicated by two dot-dash lines 102, 103. These form the flanks 100, 101, of two threaded blades. The position of the cutting groove is synchronised with the contour of the threaded tooth flank in such a way that on the one hand the end 104 of the lead threaded blade is located in front of jump point 95, and on the other hand that an overstand with a relief angle is formed on cutting edge 105 at the following threaded blade. The small bump 98 formed by the residual swing has an

amplitude which is dependent both on the mass and the control inertia of the system, as well as for example on the cutting speed used. It is, however, of practically no significance for the general effectiveness of the primarily generated protruding cutting edge and the relief angle.

The curve shown as an example in the drawing of two sequential threaded tooth flanks also includes a mutual swing of the individual threaded blades in their direction of propagation. The amount of this swing depends on the design specifications. The swing can be either minimised or completely irradicated such that only a relict of the overshoot (96) remains in the form of cutting edge 105, or a part thereof, which extends beyond the end 104 of the leading threaded blade.

The process explained with the help of drawings 13 through 15 can be applied in a corresponding fashion in for example flat threads on radial tooth heads pointing outwards as well as on other threads on two or more surfaces of the threaded tooth profile.

A further application of the process in accordance with the invention is presented in figures 16 and 17 based on an example. In this case this a so-called circular wedge coupling which is used in general mechanical engineering. Figure 16 shows a coupling sleeve 106 with a centre 107. The inner wall has three circular wedge surfaces 108, 109, 100, which abut on each other at jumps 111, 112 and 113. A journal 114 adapted to the inner profile of sleeve 106 is illustrated in figure 17. This journal has three outer circular wedge surfaces 116, 117, 118 centred around the central axis 115 which cross over into one another at jumps 119, 120, 121. The circular wedge surfaces present on both sleeve 106 and journal 114 are sections of spirals which end and begin abruptly at the respective abutment points. In order to produce these circular wedge surfaces using the process in accordance with the invention it is in principle irrelevant whether these are sections from an archimedial, a logarithmic, hyperbolic or Fermatic spiral. One would, however, generally assume that a circular wedge surface is a section from a

logarithmic spiral because this generates the most favourable material loads during clamping because of the uniform angle of pitch.

When producing inner or outer circular wedge surfaces the significant aspect is that the curvature is mainly in accordance with the specifications and that the jumps waste as little as possible of the future contact area. This task is achieved using the process in accordance with the invention including the jump system described in the preceding without any difficulties. In order to cut for example the circular wedge sleeve 106 on a CNC lathe, a suitable blank is initially predrilled and if necessary rough machined to achieve initial dimensions. The final machining using a drill rod, for example with an index cutting tool is in principle such that during workpiece rotation the tool is moved radially outwards at a slow rate of advancement to the end of the circular wedge surface and then is lifted from the circular wedge surface by a jump command directed inwards. This jump command in the program creates a tool track comprising a transitional element with an overshoot pointing towards the centre 107 which is dimensioned in the programming such that the tool is a considerable distance from the start of the next circular wedge surface. The following command blocks in the program are configured such that the next circular wedge surface is skipped and the tool is introduced to the next but one circular wedge surface when its track has settled. In the case of the example illustrated in figure 16, which requires a relative movement of the workpiece to the tool in a right-handed turn, looking in the direction of view, the machining sequence of the three circular wedge surfaces 108, 109, 110 would then for example be as follows, starting with circular wedge area 108:

108 – machine from 112 to 111
110 – skip
109 – machine from 113 to 112
108 – skip
110 – machine from 111 to 113
109 – skip

108 – machine from 112 to 111
etc.

There are a number of freedoms with respect to the configuration of the NC program in accordance with the invention. Thus for example the radial advance can be programmed as pitch, with the choice of using a superimposed modifying function, (e.g. using parameter E), or as fixed co-ordinates, in order to realise a specific form of surface curvature. As far as the axial tool movement is concerned there is the choice of either retaining the corresponding tool advance and hence using smaller advance values or only employing advance either during the cutting of the individual circular wedge surfaces or the cutting pauses during skips.

The production of the journal required for the circular wedge surfaces represents in principle the procedure described for the sleeve. An appropriate tolerance of the dimensions should be borne in mind such that both parts fit together with the requisite gap. The jump surfaces created by machining in accordance with the invention only represent such a small part of the circumference that between the fitted partners only negligible gaps are not used for the transfer of forces.

In fact the possibilities opened up by this process are virtually unlimited. They are generated by the application of CNC programs by linking with the movement of a tool fixed to a carriage with the rotation of the spindle and the inclusion or the combination of jerk values for the address parameters for diameter, length and pitch or spindle angle as well as the possibility of using a pilgrim-step technique or the described interleaved machining sequences. Thus it is now possible to run machining tasks on CNC lathes extremely rationally which previously were very time consuming and in part had to be produced in poorer surface quality by milling.

The proposed artificial hip joint sockets with special threads and threaded blades of screw surfaces with neutral angles behind the cutting edges as proposed for the

application of the process is persuasive because of the very low screw-in forces, extremely low risk of overtightening, excellent tactiliance and a for the most part gap-free transition to the bone bearing surface. A particularly advantageous model is such with a pointed thread, cutting grooves with windup and threaded blades swung relative to one another in the direction of the wind-up angle. This not only makes handling of the screw socket considerably better during implantation but also substantially increases primary and secondary fixation and hence virtually excludes the risk of premature loosening.